Received: 22 December 2018 | Revised: 3 April 2019 | Accepted: 11 April 2019

DOI: 10.1111/clr.13441

ORIGINAL ARTICLE

CLINICAL ORAL IMPLANTS RESEARCH WILEY

In vitro efficacy of three different implant surface decontamination methods in three different defect configurations

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Funding information
Noble Biocare, Grant/Award Number: 2017-1500; NSK Europe GmbH; German Society of Periodontology (Deutsche Gesellschaft für Parodontologie, DG PARO)

Abstract

Objectives: Evaluation of in vitro efficacy of three different implant surface decontamination methods in a peri-implant bone defect model.

Material and methods: A total of 180 implants were stained with indelible red color and distributed to standardized peri-implant bone defect resin models with a circumferential defect angulation of 30°, 60°, or 90° (supraosseous defect). Sixty implants were assigned to each type of defect. All implants were cleaned by the same examiner. For each type of defect, 20 implants were cleaned for 2 min with one of 3 devices: curette (CUR), sonicscaler (SOSC), or air abrasion with glycine powder (APA). Thereafter, photographs were taken from both sides of each implant and the cumulative uncleaned implant surface area was measured by color recognition technique. Scanning electron micrographs (*SEM*) were examined to assess morphologic surface damages.

Results: The cleaning efficacy as percent (%) of residual color was significantly different for each of the 3 defect angulations ($p < 0.001$) for each treatment device: 30° CUR: 53.44% > SOSC: 19.69% > APA: 8.03%; 60° CUR: 57.13% > SOSC: 11.4% > APA: 0.13%; and 90° CUR: 48.1% > SOSC: 13.07% > APA: 0.58%. The differences between the three different cleaning modalities within each defect type were also significant ($p < 0.005$). *SEM* micrographs showed no surface damages after the use of APA.

Conclusion: Air powder abrasion is the most efficient (APA > SOSC > CUR) and less surface damaging treatment modality for each defect angulation in this in vitro model.

KEYWORDS
air-flow, in vitro, peri-implantitis, surgical, treatment method

1 | INTRODUCTION

As a plaque-induced disease of peri-implant tissues, peri-implantitis leads to progressive bone loss as a result of initial mucositis and is the main cause of later implant loss (Derks & Tomasi, 2015). Consequently, peri-implant diseases have been included in the new classification of periodontal diseases (Schwarz, Derks, Monje, & Wang, 2018). The main cause of peri-implantitis is a non-specific microbial biofilm on the implant surface and superstructure, which leads to an inflammatory reaction of the surrounding peri-implant

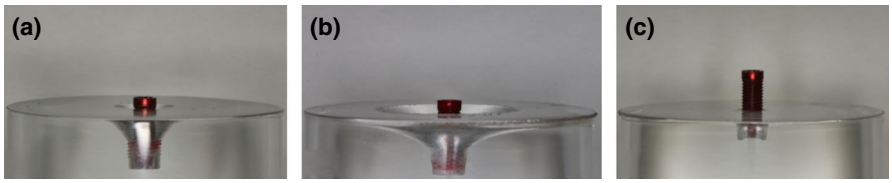

FIGURE 1 Lateral view of the different defect angulations (a) 30°, (b) 60°, and (c) 90°

tissues (Carcuac & Berglundh, 2014). Clinical signs of this inflammation include progressive peri-implant bone loss, as well as further inflammatory signs such as bleeding on probing (BOP) with/without suppuration, and increased pocket probing depths (PPD) with/without marginal mucosa recession (Schwarz et al., 2018). Poor oral hygiene, nicotine use, existing or history of periodontitis, and irregular supportive implant therapy after insertion of implants have been identified as risk factors for the development of peri-implant diseases (Derks et al., 2016; Heitz-Mayfield, 2008; Schwarz et al., 2018; Sgolastra, Petrucci, Severino, Gatto, & Monaco, 2015).

At 22% (patient-level), the incidence of peri-implantitis 20–26 years after implant insertion is high and represents a particular challenge in modern dentistry (Renvert, Lindahl, & Persson, 2018). Similar data (19.83%) were found in a systematic review and meta-analysis by Lee, Huang, Zhu, and Weltman (2017). Nevertheless, implant therapy has developed into an increasingly frequently used therapy option. In Germany, 3.4% of younger adults and 8.1% of younger seniors have dental implants. This number has almost tripled in 10 years (Jordan & Micheelis, 2016). As a consequence, cases of peri-implant diseases are increasingly occurring in everyday practice (Schmidlin et al., 2012).

Therapeutically, the only option currently available with a confirmed diagnosis of peri-implantitis, apart from explantation, is the attempt to disrupt and remove the microbial biofilm on the implant surface (Figuero, Graziani, Sanz, Herrera, & Sanz, 2014; Lang, Wilson, & Corbet, 2000; Mombelli & Lang, 1994). Different non-surgical and surgical procedures have been described (Lang et al., 2000; de Waal, Raghoebar, Meijer, Winkel, & van Winkelhoff, 2016). Surgical approaches are considered to be more effective in more advanced stages due to the peri-implant bone and defect morphology. No predictable results have been achieved with non-surgical procedures as accessibility is impeded (Renvert & Polyzois, 2015; de Waal et al., 2016). The treatment modalities for cleaning the surface range from mechanical debridement and the use of lasers to the use of air powder abrasion devices. This raises the question whether the efficacy of the individual decontamination methods depends on the morphology of the bony defect and the surface quality of the implant. Studies have already shown a superiority of air powder abrasion devices over other methods (Ronay, Merlini, Attin, Schmidlin, & Sahrmann, 2017; Sahrmann et al., 2015). Nevertheless, the data are not comprehensive and there are no comparable confirmatory studies with other implant systems and decontamination alternatives.

The aim of this study was to compare three common methods for surface decontamination of implants using an in vitro model with three different defect angulations in order to expand the available data on efficacy and to confirm existing results. In contrast to other studies, a different implant system and alternatives for the decontamination of the implant surface were deliberately chosen (Sahrmann et al., 2015). This led to the hypothesis that the treatment methods (curette, sonicscaler, and air powder abrasion) significantly differ from each other and from the simulated defect angulation (30°, 60°, and 90°).

2 | MATERIALS AND METHODS

2.1 | Implant preparation and model

The setup of the study followed the methodology described by Sahrmann et al. (2015). One hundred eighty implants with a length of 13 mm and a diameter of 4.3 mm (Replace Select Straight, Nobel Biocare AB, Göteborg, Sweden) were dipped for five seconds in red color (Staedler permanent lumocolor, Nuremberg, Germany) and air-dried for 24 hr to simulate a plaque-covered surface. The implant consisted of two surfaces: (a) a machined surface in the coronal part (1.5 mm) and (b) moderately anodized surface (rough) in the apical part. Both the anodized and the machined surface were completely and homogeneously covered.

The in vitro defect model was computer-aided designed and manufactured in three different defect angulations (30, 60 degrees as intraosseous defects, and 90 degrees as supraosseous defect) in acrylic glass (Figure 1). The implants in the intraosseous defect simulation were placed 10.75 mm (complete rough implant surface) into the models in order to simulate a supracrestal position of the machined surface. Therefore, the supraosseous defect simulation resulted in a supracrestal position of the machined and the rough implant surface (Sahrmann et al., 2015). The defect depth in the intraosseous defects was 6 mm. Every implant was surrounded by acrylic glass in the apical 4.75 mm (Figure 2).

2.2 | Simulation procedure

One of the three different cleaning methods was tested on 20 of the 60 implants per defect angle. A total of 180 implants were examined. In the process, the following instruments for surface decontamination were used (Figure 3):

- Langer curette SL 1/26 [Curette: CUR (Hu-Friedy, Chicago, Illinois, USA)] made of steel.
- Ti-Max S970 Air-Scaler [Sonicscaler: SOSC (NSK Europe GmbH, Eschborn, Germany)] with a steel tip (S20, NSK) using level 2 power output adjustment with activated irrigation (20ml/min).

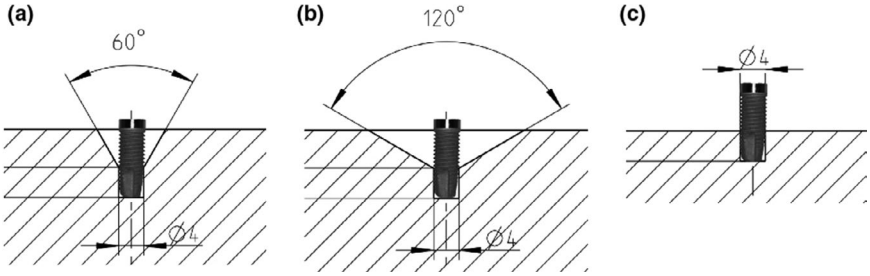

FIGURE 2 Engineering drawings of the three different defect models (a) 30°, (b) 60°, and (c) 90° each with an exemplary inserted photograph of an untreated implant (Replace Select Straight, Nobel Biocare AB, Göteborg, Sweden) 13 x 4.3 mm with 1.5 mm collar-height and 0.6 mm thread-distance

- Perio-Mate air powder abrasion unit with glycine powder [Air Powder Abrasion: APA (Perio-Mate unit with Perio-Mate Powder, NSK)] and attached Perio-Mate nozzle tip (NSK) using the medium ejection setting for powder and water spray volume.

All implants were cleaned by the same operator (DK). The cleaning time was 2 min per implant and was controlled using a stopwatch. During the cleaning process, the working distance and working angle were individually selected by the operator. After instrumentation, dissolved color remnants were removed with an air–water rinse for 10 s (Sahrmann et al., 2015).

2.3 | Photograph documentation and analysis

After each sequence, the implants were removed individually without touching the treated surfaces with the system equivalent implant driver (Implant Driver NobelReplace™ R Long, Nobel Biocare AB) and fixed in an individually fabricated and non-movable holder. Then, the implants were digitally photographed (Canon EOS 70D, Tokyo, Japan) under standardized conditions [31.4 cm distance, ISO 100, aperture f/32, exposure time 1/250 s (Sahrmann et al., 2015)] in a uniformly illuminated photograph tent (proxistar, Kastl, Germany) on both sides (180 degrees) with ring flash (Canon ring flash MR-14, Tokyo, Japan) at the same time of day (Figure 4).

The resulting 360 photographs were then analyzed by the examiner (DK) using photograph editing software (Adobe Photoshop CS6, Adobe Systems) for color remnants. Standardized values and reference patterns were used for residual color detection on the respective implant surface. Therefore, the implant surface (machined and rough) from the reference and each treated implant was once manually selected for both sides and saved as mask. Then, all treated implants were, according to the photographed side, easily selected by mask. Afterward, the reference photograph (no color remnants) was overlaid by each photo of a treated implant (with color remnants) in the "difference" mode. Basic values (brightness, contrast, and sharpness) were not changed. The before-mentioned software detected red color remnants, which were documented as percent of the whole selected implant surface.

In addition, scanning electron microscope (*SEM*) images (Philips XL 30 with lanthanum hexaboride cathode, 20 kv, 10 mm distance, Philips) of the machined and rough surfaces of one untreated implant (reference) and one treated implant for each decontamination method were exemplarily taken after instrumentation (CR; magnification 1× 1,000 and 1× 10,000). All samples were gold coated with a layer thickness of approximately 50 nm using an automatic sputtercoater (MSC2, KDF Electronic & Vacuum Services Inc.) (Figures 5 and 6).

2.4 | Statistical evaluation

The implant was considered as statistical unit. A sample size calculation was not performed. The sample size was chosen according to Sahrmann et al., 2015 with 20 implants for each defect angulation and treatment modality without a re-use of the implants. The percentage of non-cleaned surface was calculated for each implant. First, the data were tested for normal distribution using the Kolmogorov–Smirnov test. Depending on this, descriptive data (mean value, medians, lower/upper quartiles, interquartile ranges (IR), and standard deviation) were analyzed for the cleaning methods and defect sizes and the group comparisons were carried out using Kruskal–Wallis test for non-normally distributed data. By defining a p value < 0.001 as significance level, multiple testing (36 comparisons) was addressed. The statistical evaluation was carried out using the IBM® SPSS® Statistics 24 software package (IBM, Armonk, New York, USA).

The study was planned in compliance with the appropriate EQUATOR guidelines.

3 | RESULTS

The cleaning efficiency was significantly different for each defect angulation and each cleaning method. None of the investigated implant surfaces were completely free (0%) of color remnants. The

FIGURE 3 Three different cleaning methods (shown in defect angulation of 60°) (a) curette, (b) sonicscaler, and (c) air powder abrasion device (charged with glycine powder)

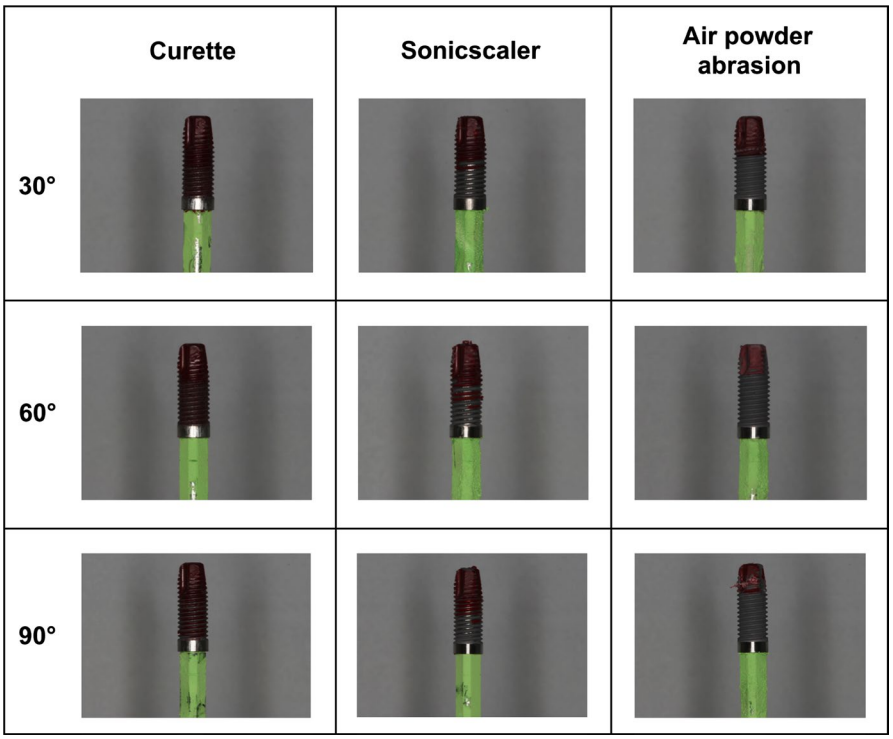

FIGURE 4 Detailed images of the cleaned surfaces according to treatment modality and defect angulation

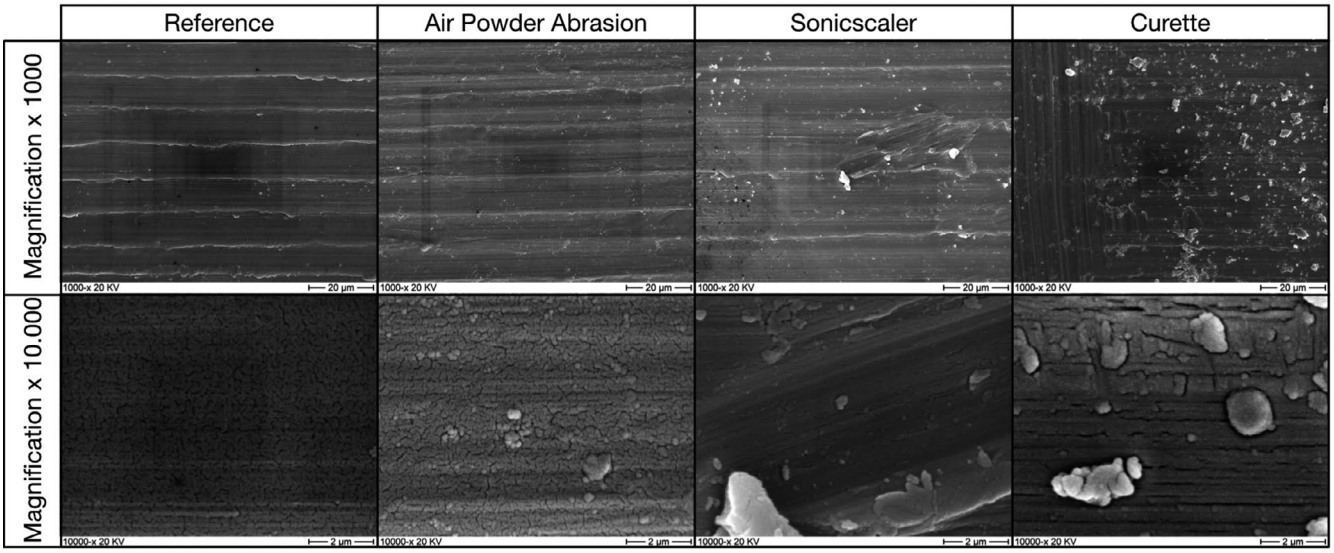

FIGURE 5 Scanning electron microscopy images of untreated (reference) and treated machined implant surfaces by different instruments at magnification of x1000 and x10.000

lower 4.75 mm of each treated implant surface was still colored because in this part the implants were surrounded by the acrylic glass model (Figures 3 and 4). Depending on the defect angulation, the APA showed the lowest color residues with a median of 8.26% (30°, IR: 2.45), 0.04% (60°, IR: 0.06), and 0.15% (90°, IR: 0.52) (Table 1). This was followed by SOSC efficacy with 20.32% (30°, IR: 4.33), 11.35% (60°, IR: 7.81), and 11.80 (90°, IR: 9.34). The CUR showed the lowest cleaning efficacy with 52.17% (30°, IR: 4.26), 59.75% (60°, IR: 7.15), and 48.97% (90°, IR: 8.37). All cleaning methods result in significantly different amounts of color remnants for all angulations ($p < 0.001$). The differences between the angulations were significant between 30° and 60° for SOSC-APA, APA-CUR, between 60° and 90° for CUR-SOSC, and between 30° and 90° for SOSC-APA, APA-CUR ($p < 0.001$) (Table 1).

When comparing percentage differences in cleaning efficacy between the methods [CUR vs. SOSC (CUR-SOSC), SOSC vs. APA (SOSC-APA), and CUR vs. APA (CUR-APA)] differences were also found (Table 2). The difference between CUR and APA was greatest in all defect angulations (30°: 45.41 ± 4.26%, 95% CI: 43.42%–47.41%; 60°: 57.01 ± 7.09%, 95% CI: 53.69%–60.33%, and 90°: 47.52 ± 5.13%, 95% CI: 45.12%–49.92%). This was followed by the one between CUR and SOSC (30°: 33.75 ± 3.88%, 95% CI:

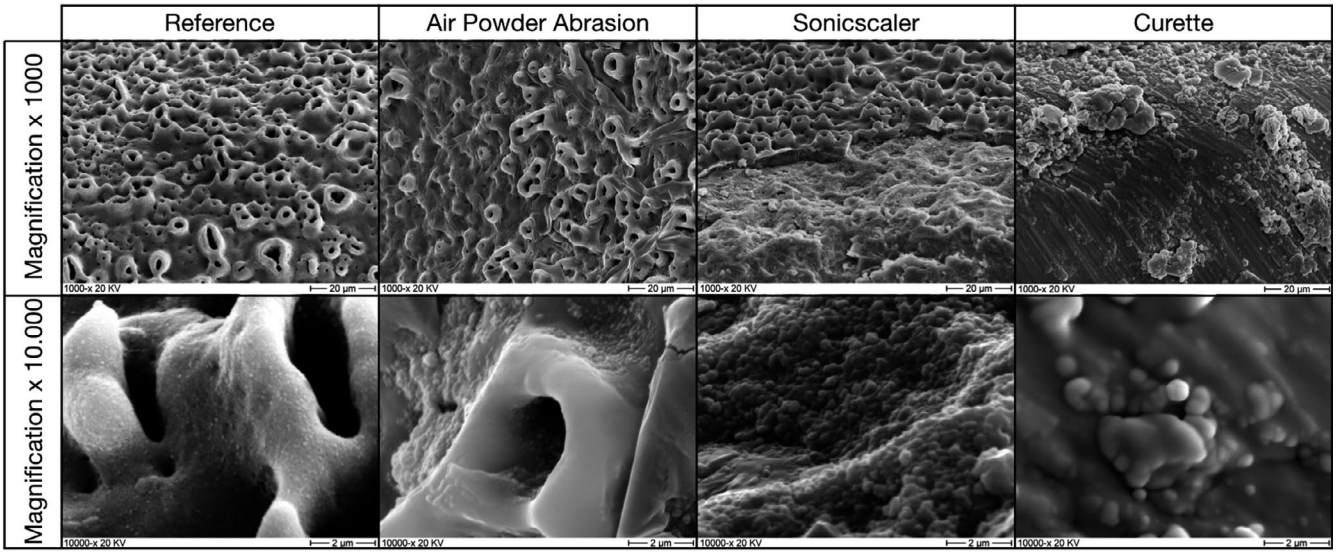

FIGURE 6 Scanning electron microscopy images of untreated (reference) and treated rough implant surfaces by different instruments at magnification of x1000 and x10.000

31.94%–35.57%; 60°: 45.73 ± 7.4%, 95% CI: 42.27%–49.19% and 90°: 35.03 ± 7.63%, 95% CI: 31.46%–38.6%). The smallest differences were found between SOSC and APA in all defect sizes.

The box plot diagram shows the decreasing cleaning efficacy of CUR < SOSC < APA and clearly demonstrates that APA has the strongest effect (Figure 7).

First of all, the *SEM* images show the complex morphology of the implant surface. After cleaning with APA, no serious substance defects were detected in the acquired *SEM* images of the implant surfaces corresponding to the damaged areas, neither on the machined nor on the rough surface. The machining rings were smoother after APA treatment than before indicating a modification of the surface (Figure 5). Moreover, the 10,000× magnification showed color remnant agglomerations or plastic particles on the surface which probably appeared from turning the implants in and out the acrylic glass models (Figures 5 and 6). SOSC and CUR, on the other hand, in the 1,000× magnification left behind implant surface damages which lead to additional sharp edges on the surface (SOSC) or accumulation of surface particles (CUR). Large defects were visible in particular on the rough surface of the implant. Compared to the reference on the rough and machined surface, the damage seemed to be greater for CUR than for SOSC (CUR > SOSC > APA). The APA in the 1,000× magnification visually kept up the integrity of the implant surface more than SOSC or CUR (Figure 6), because the whole surface with its craters seemed to be rounded down. In the 10,000× magnification (Figure 6), this difference disappeared, because the magnification was probably not exactly adjusted to the damaged surface area.

5 | DISCUSSION

With respect to the efficacy of the cleaning methods, CUR proved to be the most ineffective variant. Facilitating comparability to other studies the discussion focusses rather on mean values than on medians. The percentage of remnant color when using the CUR in this study was 53.44% for a 30° defect, which is more than twice as high compared to Sahrmann et al. (21.6%). This result was not unexpected because of the geometric and morphologic challenges which appear in daily clinical practice when a rigid curette is used for circumferential surface decontamination of peri-implant and differently angulated bone defects.

While the SOSC was for the most part equal in both studies, APA showed with 8.03% residual color at 30° angulation a clearer reduction in residual color in this study than Sahrmann et al. did with 16.1%. This could be derived from a possibly more delicate design of the nozzle tips used. The difference between APA and CUR or APA and SOSC was significant, which on the other hand is consistent with the results of similar in vitro studies (Sahrmann et al., 2015, 2013). Similar results, which confirm the lowest cleaning efficacy of different implant surfaces, were obtained in a further study that also discussed a dependence of the cleaning efficacy on different implant surfaces (Schmage et al., 2014).

Nevertheless, differences in cleaning efficacy between the two investigated implant systems comparing the present study and the study by Sahrmann et al. (2015) in terms of cleaning efficacy may be attributed to various reasons:

In order to expand the data available, a different implant type was used, which differs from the implant type used (etched and sand-blasted) in the aforementioned study in terms of the macro design and implant surface (anodized surface). The sand-blasted and acid-etched surface results in the reduction of high peaks of material with smaller craters. The anodized surface on the other hand is characterized by a microstructured morphology with open pores in the low micrometer range. This different surface texture and the resulting degree of roughness may result in different biofilm retentive properties and, hence, cleaning efficacy. The Sa values as

TABLE 1 Medians, means, and standard deviations [%] and *p* values (Kruskal–Wallis) of residual colored surface areas after treatment with three different methods: curette (CUR), sonicscaler (SOSC), air powder abrasion (APA). Separately presentation for different treatment methods and defect angulations. *N* = 20 for each treatment method in each defect angulation

	30°						60°	
			Percentile (mm)			*p* value		
Defect angulation	Min. (mm)	Max. (mm)	25th	50th (Median)	75th	(30°–60°)	Min. (mm)	Max. (mm)
CUR	49.78	60.39	51.45	52.17	55.71	0.017	35.43	64.61
Mean ± *SD* (mm)	53.44 ± 2.95						57.13 ± 7.03	
p value (CUR-SOSC)	**<0.001**						**<0.001**	
SOSC	13.58	26.18	17.38	20.32	21.71	**<0.001**	5.30	20.01
Mean ± *SD* (mm)	19.69 ± 3.14						11.4 ± 4.42	
p value (SOSC-APA)	**<0.001**						**<0.001**	
APA	3.01	15.59	6.61	8.26	9.06	**<0.001**	0.00	1.10
Mean ± *SD* (mm)	8.03 ± 2.43						0.13 ± 0.26	
p value (APA-CUR)	**<0.001**						**<0.001**	

Note: All significant results are in bold.

expression of surface roughness vary for the used implants between 1.0 and 2.0 µm (Albouy, Abrahamsson, Persson, & Berglundh, 2008). Therefore, the comparable surface roughness alone did not explain the differences in cleaning efficacy. The macro design of the Replace Select implant in particular makes cleaning and accessibility for curettes at the points below the threads more difficult due to the large number of threads (Figure 4). Furthermore, it results in a surface enlargement which also may promote a different cleaning efficacy. To what extent the different implant surface compared to Sahrmann et al. actually influenced the result cannot be conclusively answered.

The 90° defect showed within the treatment group CUR the best results. This was maybe caused by the better accessibility compared to the 30° and 60° angulations, whereas for SOSC and APA the best results were found for the 60° defect. Nevertheless these results were not significantly better than in the 90° defect. Although the accessibility should have been better in the 90° angulated defect, the more favorable results in the 60° defect were maybe achieved by reflecting the water jet or the glycine powder from the defect walls below the threads. Consequently, the results for all treatment methods in the 60° defects were better than in the 30° defects, which probably were caused by better accessibility in the wider defect.

It should also be noted that there may have been variations in details, such as immersion, drying times, and the singular use of implants. The times are not described in more detail, and the implants were re-used in the study by Sahrmann et al. (2015).

Within our investigation, the differences in cleaning efficacy are more pronounced between the decontamination methods than

TABLE 2 Medians, means, and standard deviations [%] with according *p*-values (Kruskal–Wallis) of differences in between treatment methods and defect angulations for residual colored surface areas: Difference between curette and sonicscaler (CUR-SOSC), Difference between sonicscaler and air powder abrasion (SOSC-APA), Difference between curette and air powder abrasion (CUR-APA)

	30°						60°	
			Percentile (mm)			*p* value		
Defect angulation	Min. (mm)	Max. (mm)	25th	50th (Median)	75th	(30°–60°)	Min. (mm)	Max. (mm)
CUR-SOSC	27.41	39.14	30.22	33.85	37.93	**<0.001**	28.44	55.41
Mean ± *SD* (mm)	33.75 ± 3.88						45.73 ± 7.4	
p value (CUR-SOSC—SOSC-APA)	**<0.001**						**<0.001**	
SOSC-APA	0.32	23.17	8.45	11.96	13.43	0.942	5.22	19.98
Mean ± *SD* (mm)	11.66 ± 4.7						11.28 ± 4.36	
p value (SOSC-APA—CUR-APA)	**<0.001**						**<0.001**	
CUR-APA	37.36	57.38	42.80	44.82	46.54	**<0.001**	35.35	64.58
Mean ± *SD* (mm)	45.41 ± 4.26						57.01 ± 7.09	
p value (CUR-APA—CUR_SOSC)	**<0.001**						0.004	

Note: Separately presentation for different treatment methods and defect angulations. *N* = 20 for each treatment method in each defect angulation. All significant results are in bold.

				90°					
Percentile (mm)			*p* value			Percentile (mm)			*p* value
25th	50th (Median)	75th	(60°–90°)	Min. (mm)	Max. (mm)	25th	50th (Median)	75th	(30°–90°)
54.81	59.75	61.96	**<0.001**	39.01 48.1 ± 4.64 **<0.001**	54.63	44.04	48.97	52.41	0.011
7.03	11.35	14.84	0.342	6.41 13.07 ± 5.46 **<0.001**	22.94	7.43	11.80	16.77	**<0.001**
0.02	0.04	0.08	0.66	0.00 0.58 ± 0.88 **<0.001**	3.05	0.05	0.15	0.57	**<0.001**

between the different defect angles. Thus, the medians within a used treatment method are much closer to each other than within the defect angulation (Tables 1 and 2, Figure 7). While cleaning with APA led to significantly better results for all angulations, the cleaning efficacy of APA decreased for steep defects of 30° despite the use of a nozzle tip. Accordingly, as mentioned before, the accessibility of the implant surface played a role. This has already been demonstrated in other studies for the simulation of non-surgical (Ronay et al., 2017) and surgical (Sahrmann et al., 2015) procedures.

This study assumes that the different cleaning methods are used after surgical access to the implant surface, that is, reflection of a mucoperiosteal flap. The surgical access facilitates to clean underneath the implant threads. The study does not provide information about the cleaning efficacy of the three methods with a non-surgical approach.

Finally, experience may also play a role, as could be shown by Sahrmann et al. (2015). Compared to the operator of the present study (2nd year of postgraduate training), an experienced therapist may have achieved different results under the same conditions.

SEM images were used to investigate possible damage to the implant surfaces with a reference and after different treatment modality. After instrumentation with curettes or sonicscalers, publications were able to demonstrate a change in the implant surface as it was documented in the present study. Mengel, Buns, Mengel, & Flores-de-Jacoby, 1998 showed for metal curettes and sonicscalers with universal tips in the analysis of *SEM* images a high substance removal on the surfaces of different implant

				90°					
Percentile (mm)			*p* value	Min. (mm)	Max. (mm)	Percentile (mm)			*p* value
25th	50th (Median)	75th	(60°–90°)			25th	50th (Median)	75th	(30°–90°)
40.29	46.46	52.03	0.012	21.23 35.03 ± 7.63 **<0.001**	48.22	29.93	34.33	42.17	0.004
6.97	11.30	14.79	0.942	6.21 12.49 ± 5.04 **<0.001**	22.90	7.04	11.21	16.61	0.942
53.97	59.70	61.94	0.012	36.61 47.52 ± 5.13 0.003	54.50	43.28	48.84	52.23	0.003

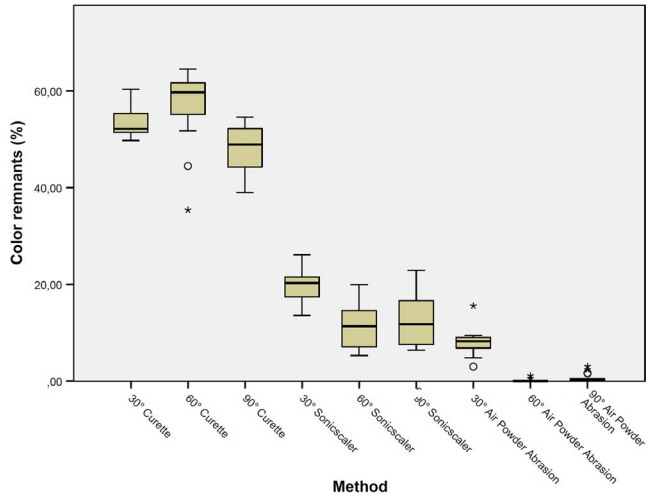

FIGURE 7 Distribution of color remnants for different treatment methods according to each defect angulation

systems (Mengel et al., 1998). These results were confirmed by further studies that described the loss of original texture and an irregular surface of titanium specimen with increasing roughness values (Schmage, Thielemann, Nergiz, Scorziello, & Pfeiffer, 2012; Unursaikhan et al., 2012). These results were confirmed by the present study. Only after using the air powder abrasion device, no comparable serious changes to those after treatment with curettes and sonicscalers on the machined (Figure 5) and rough (Figure 6) surface were detected in this study. This is in line with other existing in vitro studies (Sahrmann et al., 2015, 2013).

Clinical studies show that after contamination with bacterial plaque and instrumentation with curettes or sonicscalers implants show reduced biocompatibility (Louropoulou, Slot, & Van der Weijden, 2015). Whether this is due to incomplete decontamination of or damage to the surfaces or both is unclear. In addition to the surface roughness, the different modifications of the implant surfaces due to their production may were related to the presented results. In vivo, the implant surface itself probably leads to different peri-implant reactions on the biocompatibility. An animal study on experimental peri-implantitis models with the same implant surface as it was used in the present study concluded that spontaneous progression of experimentally induced peri-implantitis occurred at implants with different geometrical design and surface characteristics (Albouy et al., 2008). These differences may have caused different histological, inflammatory answers (Albouy, Abrahamsson, & Berglundh, 2012; Albouy, Abrahamsson, Persson, & Berglundh, 2009).

An implant surface that is contaminated by a dysbiotic biofilm may be worse than a damaged but biofilm-free surface. The best option is to remove the biofilm and to leave the titanium surface intact. For clinical practice, this seems to implicate that in the surgical treatment of peri-implant defects the use of an air powder abrasion device compared to curette and sonicscaler in all kind of aforementioned defects should be favored. However, if subgingival hard deposits (i.e., calculus) are found air powder abrasion is unlikely to remove them and curettes or sonic scaler have to be used irrespective of the damaging potential.

The following aspects must be considered as limitations of this study: On the one hand, the use of a color as "artificial plaque" in an in vitro model without simulation of further oral cavity-specific influences only allowed an approximate imitation of the clinical reality. This model was nevertheless chosen for reasons of comparability. In addition, the remaining red color made it easier to directly measure the ink remnants digitally. The photographs were evaluated from a single angle, which made a differentiation of color remnants on the upper or lower flange of the threads more inaccurate than in other investigations (Sahrmann et al., 2015).

Furthermore, contrary to clinical situations, the angle of application and type of execution were freely selectable. In vivo, this would imply previous surgical flap mobilization with good visualization of the peri-implant bone defect and corresponding experience of the surgeon (de Waal et al., 2016).

Within the limitations of this study, the results show that air powder abrasion is the most efficient (APA > SOSC > CUR) and less surface damaging treatment modality for each defect angulation in this in vitro model, which becomes less effective in steeper defects. Nevertheless, transferring the use of APA to surface decontamination in surgical peri-implantitis therapy needs further clinical studies.

ACKNOWLEDGEMENTS

The authors would like to thank Nobel Biocare (research grant 2017-1500) and NSK Europe GmbH for material support. Special thanks go to Dominik Giesa for supporting the design and fabrication of the in vitro models. This study was performed for a thesis for a Master of Science in Periodontology and Implant Therapy [German Society of Periodontology (DG PARO) and Dresden International University (DIU)]. D. Keim was granted a master scholarship by the DG PARO.

CONFLICT OF INTEREST

The authors declare no conflict of interest related to the present study. This study was in part self-funded by the authors and their institution and in part funded by a German Society of Periodontology (DG PARO) and DIU Master of Periodontology and Implant Therapy scholarship (DK). The treated implants in the present study were kindly provided by Nobel Biocare Services AG (Kloten, Switzerland) with research grant 2017–1500. NSK Europe GmbH (Eschborn, Germany) provided the Ti-Max S970 Air-Scaler including the S20 tip and the Perio-Mate including glycine powder and nozzle tips.

AUTHOR CONTRIBUTION

P.E. and B.D. conceived the ideas; D.K. and H.P. collected the data; C.R. took scanning electron microscope images; K.N. complied methodical approaches; H.P. analyzed data and managed the group; P.E., D.K., and H.P. led the writing.

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REFERENCES

Albouy, J. P., Abrahamsson, I., & Berglundh, T. (2012). Spontaneous progression of experimental peri-implantitis at implants with different surface characteristics: An experimental study in dogs. *Journal of Clinical Periodontology*, *39*, 182–187.

Albouy, J. P., Abrahamsson, I., Persson, L. G., & Berglundh, T. (2008). Spontaneous progression of peri-implantitis at different types of implants. An experimental study in dogs. I: Clinical and radiographic observations. *Clinical Oral Implants Research*, *19*, 997–1002.

Albouy, J. P., Abrahamsson, I., Persson, L. G., & Berglundh, T. (2009). Spontaneous progression of ligatured induced peri-implantitis at implants with different surface characteristics. An experimental study in dogs II: Histological observations. *Clinical Oral Implants Research*, *20*, 366–371.

Carcuac, O., & Berglundh, T. (2014). Composition of human peri-implantitis and periodontitis lesions. *Journal of Dental Research*, *93*, 1083–1088.

de Waal, Y. C., Raghoebar, G. M., Meijer, H. J., Winkel, E. G., & van Winkelhoff, A. J. (2016). Prognostic indicators for surgical peri-implantitis treatment. *Clinical Oral Implants Research*, *27*, 1485–1491.

Derks, J., Schaller, D., Hakansson, J., Wennstrom, J. L., Tomasi, C., & Berglundh, T. (2016). Effectiveness of Implant Therapy Analyzed in a Swedish Population: Prevalence of Peri-implantitis. *Journal of Dental Research*, *95*, 43–49.

Derks, J., & Tomasi, C. (2015). Peri-implant health and disease. A systematic review of current epidemiology. *Journal of Clinical Periodontology 42 Suppl*, *16*, S158–171.

Figuero, E., Graziani, F., Sanz, I., Herrera, D., & Sanz, M. (2014). Management of peri-implant mucositis and peri-implantitis. *Periodontology*, *2000*(66), 255–273.

Heitz-Mayfield, L. J. (2008). Peri-implant diseases: Diagnosis and risk indicators. *Journal of Clinical Periodontology*, *35*, 292–304.

Jordan, A. R., & Micheelis, W. (2016). *Fünfte Deutsche Mundgesundheitsstudie (DMS V)*. Köln, Germany: Institut der Deutschen Zahnärzte (IDZ).

Lang, N. P., Wilson, T. G., & Corbet, E. F. (2000). Biological complications with dental implants: Their prevention, diagnosis and treatment. *Clinical Oral Implants Research*, *11*(Suppl 1), 146–155.

Lee, C. T., Huang, Y. W., Zhu, L., & Weltman, R. (2017). Prevalences of peri-implantitis and peri-implant mucositis: Systematic review and meta-analysis. *Journal of Dentistry*, *62*, 1–12.

Louropoulou, A., Slot, D. E., & Van der Weijden, F. (2015). Influence of mechanical instruments on the biocompatibility of titanium dental implants surfaces: A systematic review. *Clinical Oral Implants Research*, *26*, 841–850.

Mengel, R., Buns, C. E., Mengel, C., & Flores-de-Jacoby, L. (1998). An in vitro study of the treatment of implant surfaces with different instruments. *International Journal of Oral Maxillofacial Implants*, *13*, 91–96.

Mombelli, A., & Lang, N. P. (1994). Microbial aspects of implant dentistry. *Periodontology*, *2000*(4), 74–80.

Renvert, S., Lindahl, C., & Persson, G. R. (2018). Occurrence of cases with peri-implant mucositis or peri-implantitis in a 21–26 years follow-up study. *Journal of Clinical Periodontology*, *45*, 233–240.

Renvert, S., & Polyzois, I. N. (2015). Clinical approaches to treat peri-implant mucositis and peri-implantitis. *Periodontology*, *2000*(68), 369–404.

Ronay, V., Merlini, A., Attin, T., Schmidlin, P. R., & Sahrmann, P. (2017). In vitro cleaning potential of three implant debridement methods. Simulation of the non-surgical approach. *Clinical Oral Implants Research*, *28*, 151–155.

Sahrmann, P., Ronay, V., Hofer, D., Attin, T., Jung, R. E., & Schmidlin, P. R. (2015). In vitro cleaning potential of three different implant debridement methods. *Clinical Oral Implants Research*, *26*, 314–319.

Sahrmann, P., Ronay, V., Sener, B., Jung, R. E., Attin, T., & Schmidlin, P. R. (2013). Cleaning potential of glycine air-flow application in an in vitro peri-implantitis model. *Clinical Oral Implants Research*, *24*, 666–670.

Schmage, P., Kahili, F., Nergiz, I., Scorziello, T. M., Platzer, U., & Pfeiffer, P. (2014). Cleaning effectiveness of implant prophylaxis instruments. *International Journal of Oral and Maxillofacial Implants*, *29*, 331–337.

Schmage, P., Thielemann, J., Nergiz, I., Scorziello, T. M., & Pfeiffer, P. (2012). Effects of 10 cleaning instruments on four different implant surfaces. *International Journal of Oral and Maxillofacial Implants*, *27*, 308–317.

Schmidlin, P. R., Sahrmann, P., Ramel, C., Imfeld, T., Muller, J., Roos, M., & Jung, R. E. (2012). Peri-implantitis prevalence and treatment in implant-oriented private practices: A cross-sectional postal and Internet survey. *Schweizer Monatsschrift Für Zahnmedizin*, *122*, 1136–1144.

Schwarz, F., Derks, J., Monje, A., & Wang, H. L. (2018). Peri-implantitis. *Journal of Periodontology*, *89*(Suppl 1), S267–S290.

Sgolastra, F., Petrucci, A., Severino, M., Gatto, R., & Monaco, A. (2015). Periodontitis, implant loss and peri-implantitis. *A meta-analysis. Clinical Oral Implants Research*, *26*, e8–e16.

Unursaikhan, O., Lee, J. S., Cha, J. K., Park, J. C., Jung, U. W., Kim, C. S., … Choi, S. H. (2012). Comparative evaluation of roughness of titanium surfaces treated by different hygiene instruments. *Journal of Periodontal and Implant Science*, *42*, 88–94.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Keim D, Nickles K, Dannewitz B, Ratka C, Eickholz P, Petsos H. In vitro efficacy of three different implant surface decontamination methods in three different defect configurations. *Clin Oral Impl Res*. 2019;00:1–9. https://doi.org/10.1111/clr.13441